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PHYSICS.—*Electrical messages from the earth: their reception and interpretation.*[1] O. H. GISH, Department of Terrestrial Magnetism, Carnegie Institution of Washington.

Electrical messages were first received from the earth early in the last century. Joseph Henry in America and Michael Faraday in England had made their notable discovery of electromagnetic induction about a decade and a half before. S. F. B. Morse, just 100 years ago, had invented the first practical telegraph. Then nine years later, in 1844, the first commercial telegraph-system was put in operation between New York, and Washington. In the next few years similar systems sprang up in various parts of the world. When sending messages on these systems there occasionally appeared other signals which sometimes became so frequent and intense as to seriously interfere with the sending of telegrams. A visitation of these intruding signals was usually widespread, coming at about the same time and running much the same course everywhere. Close observation of the signals which intruded on the lines of the British system led W. H. Barlow to conclude in 1847 that they come from the earth, that such signals may be received at any time, but that they are usually not intense enough to interfere with the telegraph-service. When submarine cables came into use, disturbing signals were also noted on them at the same time as the great disturbances on land lines. Disturbances of this sort were accompanied by erratic agitation of the compass-needle, and frequently by unusual displays of polar lights. These intruding signals constitute the electric messages from the earth which are the theme of this paper.

It was soon recognized that these signals resulted from electric currents of some natural origin which circulate in the earth, branch through telegraph-lines, and, when intense enough, actuate the receiving instruments and sometimes even damage them. The occasions when the electric earth-currents are intense and unusually agitated are termed storms, earth-current storms, not because of any connec-

[1] Address of the retiring president, delivered before the Philosophical Society of Washington, January 4, 1936. Received April 3, 1936.

tion with weather, for there is none, but rather for about the same reason that an emotional outburst is so designated.

One of the more intense of these storms occurred in 1859. All the grounded telegraph-lines of the world were apparently affected by that storm. During most of a seven-day period from August 29 to September 4 it was impossible to send telegrams. However, occasionally these currents were sufficiently intense and so steady that they could be used instead of the usual batteries for operating the telegraph-instruments. On September 2, the line from Portland, Maine, to Boston, Massachusetts, spanning a distance of 110 miles, was *worked* by the earth-currents alone, commercial messages being sent from 8 to 10 a.m. The line between Fall River and South Braintree, Massachusetts, a distance of 40 miles, was also worked in the same way. A message was also sent in this manner between Philadelphia and Pittsburgh. In some cases the strength of the current during this storm was roughly determined. Thus it was reported that on one line in France, which spanned a distance of 600 km the current "was equal to that produced by a battery of 800 volts." In Norway the disturbance to the telegraph was said to have been greater than in other parts of Europe. During this electric commotion the compass-needle was everywhere visibly agitated. At Rome it changed direction 4° 13′ in a half hour and the horizontal magnetic force changed by one-eighth its whole value. Extraordinary displays of polar lights were also reported. The aurora borealis was seen as far south as 18° north latitude and at higher latitudes the brilliance of these lights was said to "nearly equal the light of the full moon." Except for the unusual duration and intensity of this storm and the accompanying magnetic and auroral manifestations, this description would apply to many other similar events. The association of the aurora borealis with such disturbances to the telegraph-service has been noted by telegraph operators in some parts of the United States who refer to such an event as an *aurora on the line*. However, the relationship is not as direct as that expression would imply.

These impulsive electric messages, which signalize earth-current storms, come only a relatively small part of the time, on the average about 16 days a year. The rest of the time electric messages of a quite different type may be received—messages of a more tranquil nature which are patiently repeated day after day, year after year. However, the electric currents which convey them are so weak that some care is required to receive them without such distortion as may lead to misinterpretation. Because some aspects of the method of receiving

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these messages have important bearing on their interpretation, it seems appropriate to describe here some of the essential features of what in technical parlance is called an earth-current measuring system.

It was early recognized that systematic observations were required for satisfactorily investigating these phenomena. The telegraph-systems by means of which the first evidence for the existence of earth-currents was obtained suggested the gross features of the arrangements used, even up to the present time. The first continuous registration of earth-currents was begun at Greenwich Observatory in 1865 under the direction of Astronomer Royal G. B. Airy. The arrangement may be described as two special telegraph-lines, with the two ends of each line connected to earth and with a galvanometer substituted for each of the telegraph-receivers. One of these lines extended from the Observatory eastward to Dartford, a distance of 9.76 miles; the other from the Observatory southward to Croydon, a distance of 8 miles. The contact to earth was made by soldering the wires to water-pipes. The deflections of the galvanometers were registered photographically. From the two components thus registered the direction of the earth-current and the intensity of the impelling force, the potential gradient, was determined. To the casual observer this system would seem equivalent to the most carefully installed modern one (the gross features of such being suggested by Fig. 1) but the reliability of the results obtained from the two different systems may not be at all comparable. The basis for this statement shall be indicated shortly.

Systematic observation of earth-currents was apparently stimulated by recommendations made by the Electrical Congress which met in Paris in 1881. Soon after this observations were started in France, Germany, Norway, Finland, Russia, Italy, and Bulgaria. Bachmetjew, in Bulgaria, used small spans, 80 to 200 meters in length. The longest spans were those in Germany where the Earth-current Committee used two underground telegraph-cables—one extending from Berlin southward to Dresden, a distance of 120 km, the other extending from Berlin eastward to Thorn, a distance of 262 km. Registration at Berlin began in 1883 and was continued until 1891. The records for the first five years were evaluated and analyzed by Weinstein, whose report stood as the outstanding contribution to the subject for several decades. In 1910 such observations were started at the Ebro Observatory, near Tortosa, Spain, where they have been continued with but little interruption up to the present time, thus

providing a body of data of much value. The net outcome of all these endeavors, as it appeared about a decade ago, may be summed up figuratively as follows: The impulsive messages received at these dif-

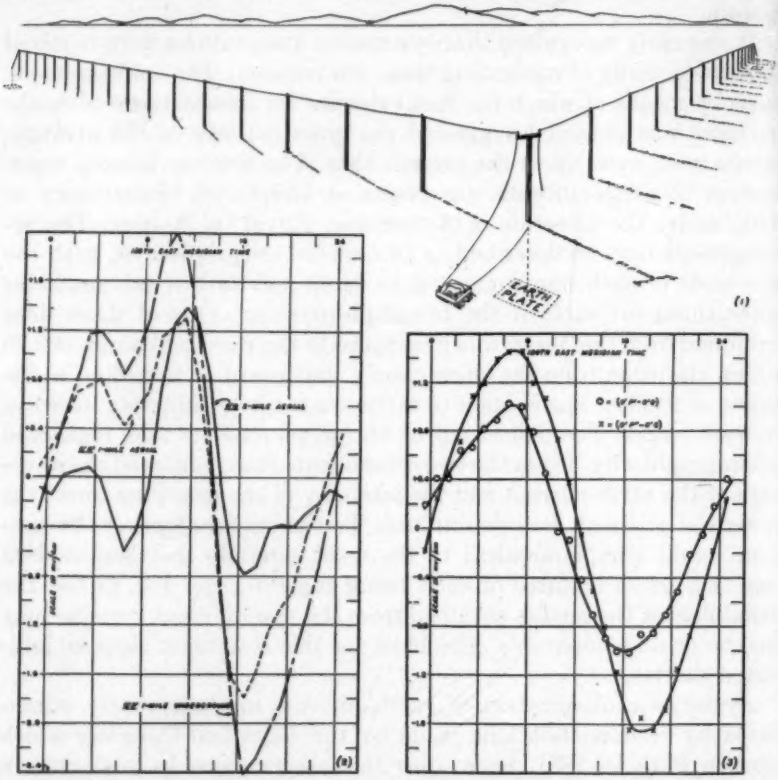


Fig. 1.—The receiving *antennae*. The conspicuous part of a simple arrangement for *receiving electrical messages* from the earth resembles two telegraph-lines which extend in different directions. These lines serve only to connect the pairs of earthed points with instruments which register the difference of potential between pairs of points.

Fig. 2.—Inconsistent *messages*. These *messages* which were received at Watheroo, January 1927, are shown here for the purpose of stressing the thesis that considerable care is required in order to receive the signals, or to record the potentials, without thereby introducing an irrelevant part which may hopelessly complicate interpretation.

Fig. 3.—Avoidable irrelevant *messages*. The inconsistent parts of the variation in the apparent gradients shown in Fig. 2 are represented in these graphs.

ferent places conveyed a fairly consistent story but the more tranquil messages were not in general agreement, only those received at Berlin and those received at the Ebro Observatory being in fair accord.[2]

[2] General references: (*a*) J. Bosler, *Les courants telluriques, Traité d'électricité atmosphérique et tellurique, publié sous la direction de E. Mathias*, 453–498 (1924); (*b*)

Such was the status in 1922 when the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in order to further its program for investigating the electrical and magnetic phenomena of the earth, installed an earth-current measuring system at its magnetic observatory near Watheroo, Western Australia.[3,4] Since then this activity of the Department has been extended, first by establishing another system at its observatory near Huancayo, Peru, in 1925.[5] Later through cooperation with the United States Coast and Geodetic Survey and the American Telephone and Telegraph Company the registration of earth-currents was begun in 1931 at the Coast and Geodetic Survey magnetic observatory near Tucson, Arizona.[6] Registrations were also obtained at College, Alaska, from August 1932 to June 1934, through cooperation with the United States Coast and Geodetic Survey and the University of Alaska,[7] and at Chesterfield, Inlet, Canada, through cooperation with the Meteorological Service of Canada.[8] The data from the two latter stations are of special significance because these places are both close to the Arctic Circle and because these projects were a part of that remarkable international cooperative program known as the Second International Polar Year. Telephone and telegraph organizations have naturally been interested in these electric currents for a long time, but as a rule they have made no extended investigation of this class of phenomena. However, the Bell Telephone Laboratories have made a notable exception to the rule by conducting registrations of earth-currents during recent years at a number of places in the United States.[9] Some systematic measments have also been made during the past decade in Sweden.[10] Dr. G. C. Southworth of the Bell Telephone Laboratories, in consultation with members of the Department of Terrestrial Magnetism, planned

J. E. BURBANK, Terr. Mag., **10**: 23–49 (1905); (*c*) A. NIPPOLDT, *Erdmagnetismus, Erdstrom, und Polarlicht, Sammlung Göschen* No. 175 (1921); (*d*) J. BARTELS, *Handbuch der Experimentalphysik*, **25**: *I*, 645–647 (1928); (*e*) B. Gutenberg, *Lehrbuch der Geophysik*, 429–433 (1929); (*f*) *Earth-currents*, Encyc. Brit., 14th ed., **7**: 837–841 (1929); (*g*) O. H. GISH, *Natural electric currents in the Earth's crust*, Sci. Mon., **32**: 5–21 (1931); (*h*) O. H. GISH, *Les courants électriques naturels de l'écorce de la Terre et leur rapport avec le magnétisme terrestre*, Cong. Internat. d'Electricité, Paris, 11e Sec., Comm. No. 1-C-2 (1932).

References (*a*) and (*b*) contain thorough bibliographies up to the dates of their publication. Reference (*h*) cites original articles for the years 1925 to 1931, inclusive.

[3] O. H. GISH, Terr. Mag., **28**: 89–108. 1923.

[4] O. H. GISH and W. J. ROONEY, Terr. Mag., **33**: 79–90. 1928.

[5] O. H. GISH and W. J. ROONEY, Terr. Mag., **35**: 213–224. 1930.

[6] W. J. ROONEY, Terr. Mag., **40**: 183–192. 1935.

[7] W. J. ROONEY and K. L. SHERMAN, Terr. Mag., **39**: 187–199. 1934.

[8] B. W. CURRIE, Terr. Mag., **39**: 293–297. 1934.

[9] G. C. SOUTHWORTH, Terr. Mag., **40**: 237–254. 1935.

[10] D. STENQUIST, *Étude des courants telluriques Mém. Direction Gén.Télégr.*, Stockholm, Fasc. 1, (1925). Fasc. 2 (1930); Terr. Mag., **32**: 143–145 (1927), **33**: 205–209 (1928).

the program and devised the means by which long-distance telephone-lines could be used satisfactorily for this work without interfering with the use of the lines for telephone-service.

The tranquil messages received in these more recent endeavors are in reasonably good agreement among themselves and also with those obtained at Berlin and at the Ebro Observatory. This outcome instills confidence in the technique which has been developed for receiving them and enables one now to better grasp the broader significance of these messages.

The features of this technique which deserve mention here pertain to the elimination of distorting effects of local origin, especially those which depend upon the manner of making the electrical contact with the Earth. In the installation at Greenwich, it will be recalled, that was accomplished by soldering the connecting wires to water-pipes. Plates of metals or coils of wire have been variously used instead of the water-pipes. Sometimes these electrodes are surrounded by charcoal or clay obtained from a common source, or a metal is suspended in a solution of one of its salts, the whole being contained in a porous jar, which is imbedded in earth. These are some of the means used in an attempt to avoid the *battery-effect* which generally exists between two plates of metal or other material when placed in earth. Even when all practical precautions are exercised, these effects may still be great enough to introduce important error in measurements of the character here considered.

These contact electromotive forces or more briefly contact-potentials must be recognized for what they are and constantly kept in mind by investigators in order that interpretations be not confused by this extraneous feature. Although it has not been found possible to entirely eliminate such effects, yet it is feasible to control them within certain limits and to an extent such that their effect may not confuse the measurements of what seem to be the more important aspects of the true earth-currents. That this is possible has been clearly shown by results obtained at the Watheroo Magnetic Observatory.[11] There, as in all installations which have been made under the guidance of the Department of Terrestrial Magnetism, pure lead wire or tubing is used as the material for making the contact with earth. This in the form of a flat spiral, or web, is placed in the earth five or ten feet below the surface and compactly imbedded in clay,

[11] O. H. Gish, Carnegie Inst. Wash. Year Book 27, 253–254 (1928); also C. R. Assemblée de Prague, 1927, Union Géod, Geéophys. Internat., Sec. Mag. Electr. Terr., Bull. No. 7, 247 (1929).

which in some cases is carted to the place for that purpose. The wire which leads from this electrode to the conducting line is very carefully insulated from the surrounding earth so that the entire contact with earth is confined to the lead web at a depth where no appreciable short-time changes of temperature, humidity, soil-moisture, etc., occur, and where mechanical action resulting from operations on the surface can exercise only a minor influence on the electrode. However, even after all precautions are taken, the slowly changing environment of the electrode may give rise to conspicuous changes in the contact-potential of the electrodes. The net effect of these upon the data derived from the measurements may be reduced by placing the points of contact farther apart, thereby increasing the part contributed to a given measurement by the true earth-current without a corresponding increase in that extraneous effect which is brought forth by the electrodes.

The question may arise as to how these extraneous effects can be detected in the measurements or registrations. The answer to this calls for a description of another feature first used systematically at the Watheroo Magnetic Observatory and later at the Huancayo Magnetic Observatory. The points for contact with the earth at Watheroo were selected so as to lie on true north-south and true east-west lines, respectively. Two pairs of points for each of these directions are now in use there (earlier there were three). Their positions and the distances they span differ. Thus two independent records for each component of the earth-current gradient are obtained. If it is found by comparing these that the variations in the gradients are nearly equal, then it is almost certain that they are free from important spurious effects arising from the electrodes. For it is not to be expected that the conditions which give rise to variations in the electrode-potentials vary with position in just the manner required to yield the same variations in gradients derived from two different pairs of points which represent different spans on the earth. The potentials which characterize the earth-currents may, however, be expected to be such a function of position. Thus on the average one might expect the electrode-effects to be a smaller part of the measured gradient when the span between points is great. The nature of some spurious electrode-effects and the manner in which they may be detected are illustrated by graphs constructed from data obtained at Watheroo.[12] These, which appear in Fig. 2, show variations during the day which are different for three pairs of points so situated that they should yield the north-

[12] W. J. ROONEY, Terr. Mag. 37: 363–374. 1932.

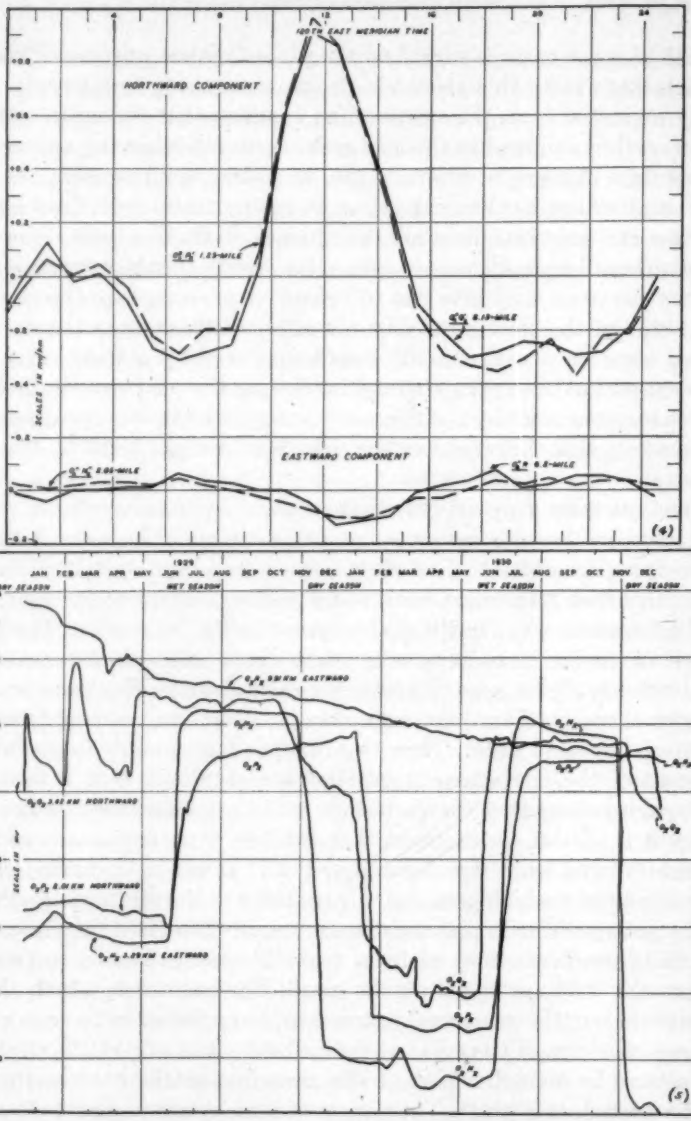


Fig. 4.—Consistent *messages*. These were obtained at Watheroo in December 1927 after improving the receiving system. They show that inconsistencies such as are exhibited in Fig. 3 may be avoided and a high degree of consistency realized when suitable care is exercised.

Fig. 5.—Unavoidable irrelevant *messages*. The daily means of potentials registered at Watheroo during 1929 and 1930, shown in these graphs, have no common characteristic such as should be noticeable if they were related to a general flow of electricity in the earth.

ward component of the earth-current gradient. Those drawn in broken lines are obtained between points one mile apart, whereas that drawn solid is for a span of two miles. Since in computing the gradients, here expressed in millivolts per kilometer, the measured differences of potential are divided by the distance between the points, any effect which may not depend on distance would tend to be less in the case of the longer span. For this and other reasons the data for the longer span are regarded as relatively free from extraneous effects. If then one subtracts the values represented by the solid curve from corresponding values on the broken curves the differences should, in a measure, represent the extraneous effects. The differences thus obtained are shown graphically in Fig. 3. One striking feature of these difference-graphs is their consistent nature and the similarity in character. They show a remarkable resemblance to the diurnal change in temperature at that place with, however, some lag in phase.[13] Certain possible sources of these effects as suggested by this observation were examined and it was found that by improving the insulation of the buried portion of the copper conductor, which joins the line with the lead electrode, this feature could be completely eliminated. However, the resistance of the original electrodes was greater than desired, it being at times as much as 2000 ohms per electrode. This necessitated that the insulation between the copper conductor and the adjacent earth be better than with electrodes having lower resistance. Because of this and other considerations, an attempt was made to install new electrodes in such manner and position that they should have much lower resistance. The agreement obtained after these improvements were effected is shown in Fig. 4. While the evidence here shown demonstrates the possibility of obtaining satisfactory measurements of the more quiet aspects of earth-currents, yet it should also indicate the caution which must be exercised if gross errors are to be avoided.

It is, however, not generally feasible to eliminate slower changes of the electrode-potentials. The character of these slower changes as observed at Watheroo are shown in Fig. 5. The ordinates in these graphs are daily means of the measured potential-differences (not gradients); positive values signify that the reference-point is at a higher potential than one to the east or to the north of it. When one observes that the absolute values as well as the changes in these potentials are generally independent of the distance and also of the direction of a point with respect to the reference-point, he necessarily concludes that the more constant part of these measured values, the

[13] O. H. GISH, Carnegie Inst. Wash. Year Book 24: 214–215. 1925.

daily mean, arises mainly from electrochemical effects of local origin and that this part of the measured quantity should therefore not be regarded as significant. These data give no indication of earth-cur-

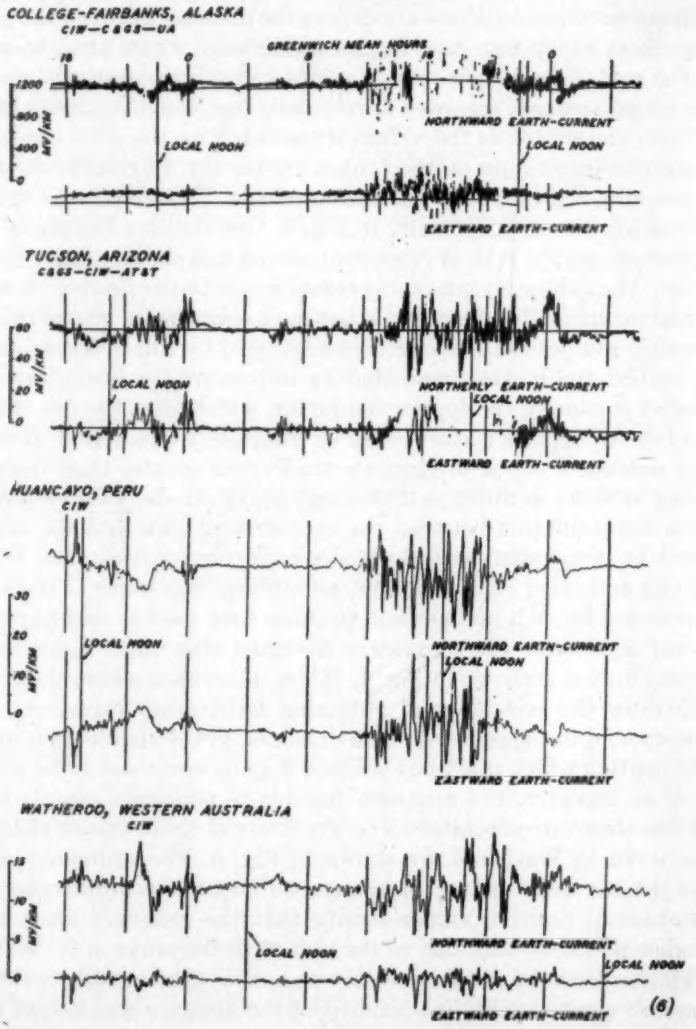


Fig. 6.—Impulsive *messages*. Such as these, which were received April 30 to May 2, 1933, at four places ranging in latitude from 65° north to 30° south, announce events which occur simultaneously over the entire earth.

rents which maintain a constant direction and intensity at a given place. It may also be mentioned that the results obtained at the Huancayo Magnetic Observatory bear this out, but stronger evidence bearing on this point is obtained at the Tucson Observatory, where the lengths of lines are 57 km in the northerly direction and 94 km in the easterly. There the steady part never exceeds 20 per cent of

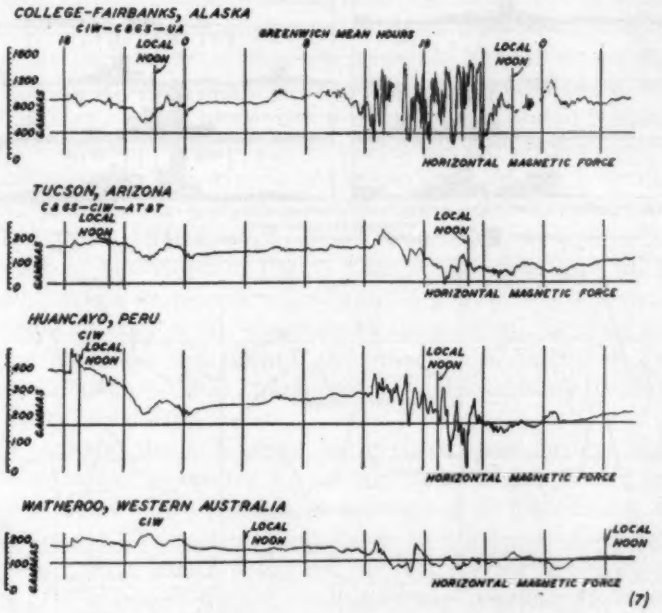
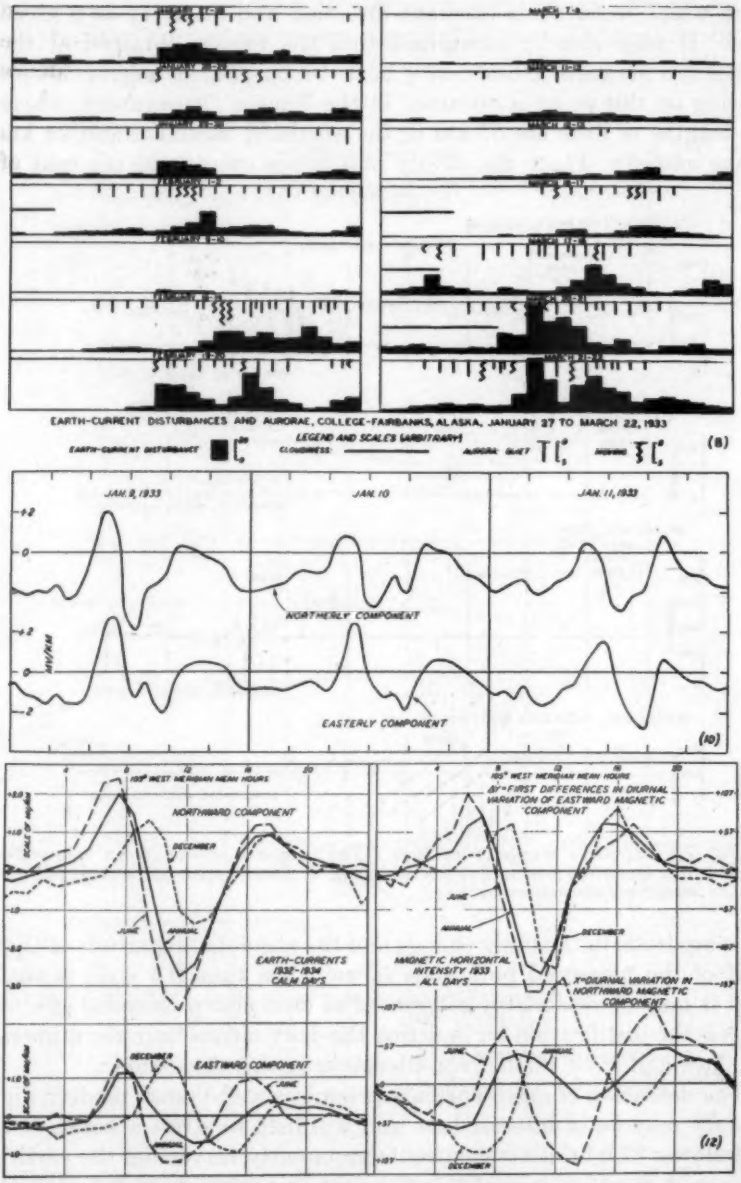


Fig. 7.—Impulsive magnetic *messages*. The magnetic effects shown here correspond to the electrical messages exhibited in Fig. 6. These appear to be magnetic and electric versions of the same narrative.

the amplitude in the daily change and the absolute magnitude of that part of the measured potentials (always less than 0.3 volt) is such that it may be reasonably attributed to local electrochemical effects. This is the justification for omitting the daily means from the numerical data and from further consideration in this discussion.

The definition of earth-currents given in a well-known modern dictionary may be of interest here and will help to stress a point. It is as follows: "Light electric currents apparently traversing the earth's surface, but which in reality only exist in a wire grounded at both ends, due to small potential-differences between the two points at



For explanation of Figs. 8, 10, and 12, see bottom of opposite page.

which the wire is grounded." Although this is not a model definition either as regards content or form of expression, yet the inaccuracy of the content may perhaps be excused on the ground that all so-called earth-current measurements contain an irrelevant element which may be dominant unless recognized for what it is. If then such nondescript grist is innocently put through a crude statistical mill, the meal which comes out may indeed spoil the pudding. One who is about to investigate these phenomena of the earth would do well to start with the attitude of skepticism expressed in this definition, an attitude also recommended for more general application by Francis Bacon when he wrote, "If a man will begin with certainties, he shall end in doubts; but if he is content to begin with doubts, he shall end in certainties."

The information now accumulated enables one to view some of the broader aspects of the system of electric currents which circulate in the earth. One sees that most earth-current storms which are observed in the middle latitudes occur simultaneously everywhere on the earth as illustrated in Fig. 6. Comparing these with the corresponding magnetic records reproduced in Fig. 7, one notices a pronounced similarity in the character of the magnetic and the electric records. When one is disturbed, the other is also disturbed. This, as well as the similarity in the character of the disturbances, is obviously not a mere coincidence.

The correspondence between the occurrence of aurorae and disturbances in earth-currents is represented by Fig. 8. Here the dark blocks represent by their height the degree of disturbance in the earth-currents. The vertical lines above these indicate the occurrence of aurorae, their length being proportional to the brilliance of the aurora. The zigzags indicate moving forms.[7] Further evidence of a relationship between earth-currents, aurora, and possibly solar activity is presented in Fig. 9. This is the result of a statistical study which was designed to determine whether there is a tendency for earth-current storms or polar lights to recur after a period of time, a sort of return engagement.[14] The curves in the right-hand side of

[14] W. J. PETERS and C. C. ENNIS, Terr. Mag., 31: 57–70. 1926. H. U. Sverdrup, Res. Dep. Terr. Mag., 6: 510–512. 1927.

Fig. 8.—Electrical *messages* pertaining to polar lights. Displays of polar lights and certain electrical effects observed at College, Alaska, January 27 to March 22, 1933, appear to be related.

Fig. 10.—Tranquil *messages*. This specimen received at Tucson, Arizona, January 9 to 11, 1933, represents a type of message which is repeated day after day, year after year. Such messages vary in intensity with the seasons and may be obscured on occasions when impulsive messages are interjected.

Fig. 12.—Character changes with season. This is especially pronounced at Tucson in both the electric and the magnetic elements, and is equivalent to a shift of latitude.

Fig. 9 indicate the relative frequency at which a storm may follow another storm at intervals of 25 to 33 days. It is noticed that this frequency is greatest at about 27 days after the first occurrence in the case of earth-currents. Although for the aurora the indications are not so positive, yet there appears to be some evidence of a similar recurrence. It should be recalled in this connection that 27 days is the time required for a sunspot to rotate with the sun. A relationship is also found between the variations in earth-currents, the activity of

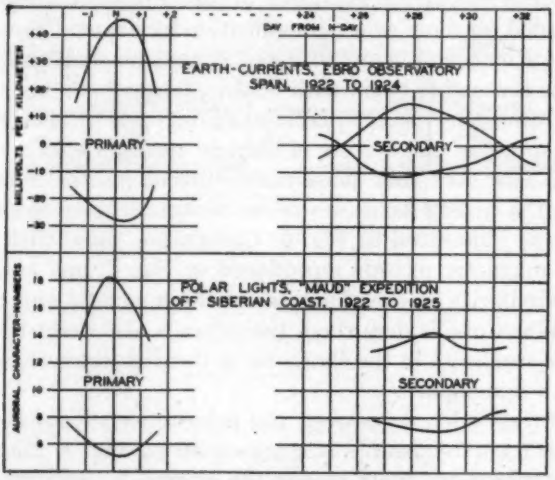


Fig. 9.—Impulsive *messages* repeat. The evidence presented in this chart shows that if an impulsive *message* (an earth-current storm) is received on a certain day, then there is a high probability that another will be received 27 days later. A similar tendency is found for terrestrial magnetism and for polar lights.

the earth's magnetism, and the occurrence of spots on the face of the sun.[15] They all run through a cycle which has a period of roughly eleven years. When sunspots are numerous, magnetic changes are greater and more frequent, and the earth-currents undergo more intense and more frequent fluctuations than at times when sunspots are less plentiful. From such observations one concludes that these earth-current disturbances must arise out of an influence which is capable of acting directly on the whole earth at once and that the activity on the sun in some way influences the electric currents in the earth.

When one examines the more quiet aspects of earth-currents, he finds there regular changes during the day such as appear in Fig. 10. These undergo some modifications from season to season, and they

[15] O. H. Gish, Sci. Mon., 32: 5–21. 1931.

wax and wane during the years.[15] The average character of the more tranquil changes observed at Tucson, Arizona, are shown by the graphs in Fig. 12. If the amplitudes of these wave-like graphs are chartered for different places and different times of the year, graphs such as those shown in Fig. 11 are obtained. It will be seen from this that the amplitude is a minimum in midwinter whether the stations be north or south of the equator and that in general the values for summer tend to be high, yet there appears to be a tendency for large

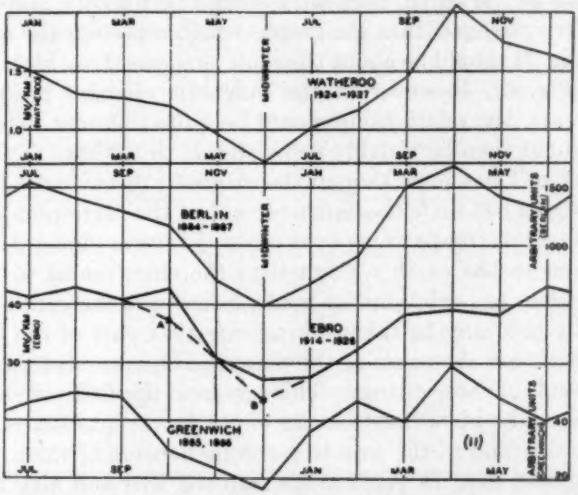


Fig. 11.—Intensity changes with season. The tranquil electric effects are generally more intense in summer than in winter.

values to occur near the time of the equinoxes. There is also evidence that the amplitude of daily change varies with a period of about eleven years and that this corresponds approximately with the variations in sunspot number.[16] The diurnal changes in earth-currents and terrestrial magnetism at Tucson, Arizona, are compared in Fig. 12. Several points of correspondence will be noted in these. The rate of the diurnal change in the westward magnetic component closely resembles the diurnal change in the northward earth-current component. The manner in which both the magnetic and the electric effects change with season at this station is of special interest in that it reveals a further relationship between these two classes of phenomena.

When one attempts to ascertain from the data just what relation-

[16] Carnegie Inst. Wash. Year Book 34: 234. 1935.

ship exists between earth-currents and terrestrial magnetism, he is confronted with some difficulty. This is especially pronounced in the case of earth-current and magnetic storms. During these storms the changes in the earth-currents are sometimes of the same character as those in the corresponding component of terrestrial magnetism, the two increasing or decreasing in unison (see Figs. 6 and 7). Then again they differ considerably in character although the duration of the disturbed periods corresponds. If the magnetic changes were due to electric currents in the earth, then they should be roughly proportional to the electric changes; thus the graphs which represent the magnetic changes (Fig. 7) should be about the same shape as those for the earth-currents (Fig. 6). However, if the magnetic changes produce the earth-currents, the relationship would be quite different. The earth-currents would then be roughly proportional to the rate of the magnetic changes. Thus, even though the magnetic disturbance be large, if it is changing but little the earth-current at the corresponding time would be small. A comparison of the observed storm-changes in earth-currents and in the earth's magnetism therefore seems to indicate that sometimes one relationship holds, sometimes the other. Viewed superficially this may be taken to indicate that part of the time the earth-currents are the cause of the magnetic changes and part of the time the result of those changes. This apparent duplicity of character, together with the inconstant nature of earth-current storms, are obstacles which stand in the way to a comprehension of them. Since it is not proposed here to venture far into the free and airy realm of speculation, we shall leave this aspect and turn to a further examination of the relation between the more quiet aspects of earth-currents and the corresponding changes in terrestrial magnetism.

When one compares the diurnal variations in these two phenomena, he finds some evidence for the view that the slow periodic changes in earth-currents may be in the main induced by magnetic changes similar to those observed. Thus in Fig. 12 it is seen that the rate of change of the eastward magnetic force at Tucson is of a very similar character to the variations in the northward component of the earth-currents.[6] Such simple comparisons are of course inadequate for more than one reason.

Any electric current must produce some magnetic effect so that it is reasonable to expect that the magnetic changes are not wholly independent of the earth-currents which seem in some way to arise from the magnetic changes. The mathematical relations which take into account such reactions between the inducing magnetic changes and

the induced current were worked out by Chapman and Whitehead.[17] That relation enables one to calculate the components of the earth-currents, or rather the gradient which is proportional to them, from

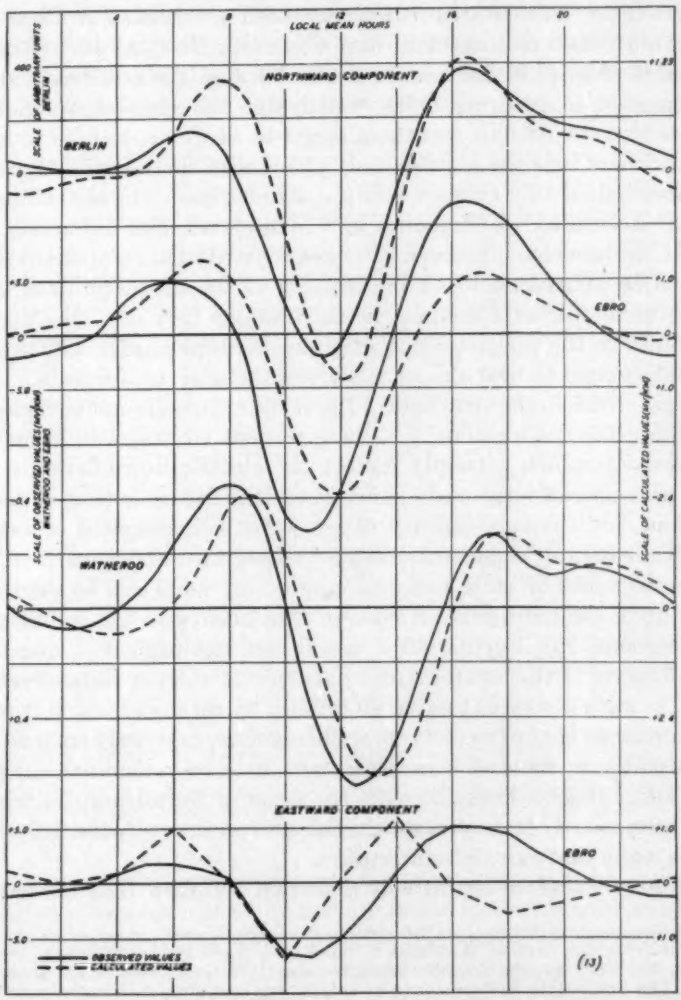


Fig. 13.—A *prediction* after the event. The solid curves represent the average diurnal-variation in the tranquil electric effects. The broken lines are those *predicted* wholly from the tranquil diurnal-changes in terrestrial magnetism.

[17] Cambridge, Trans. Phil. Soc., **22**: 463–482. 1922.

the observed magnetic changes. In Fig. 13 these calculated values of the earth-potential gradient are compared with those which have been observed.[18] There seems to be fair qualitative agreement for the northward component but not for the eastward component. The values calculated for Watheroo are six times those observed. For Ebro the calculated values are one-fifth those observed. No quantitative comparison is possible in the case of Berlin because the observed values are expressed in arbitrary units.[17a] Although the agreement is not as good as one should like, yet there seems to be evidence here to support the view that the regular daily changes in earth-currents are in the main induced by corresponding daily changes in terrestrial magnetism. According to Chapman and Whitehead, the difference between calculated and observed values of the eastward component may perhaps be attributed to an inadequacy of the magnetic data. Referring to the formula used in the calculations they say "the higher harmonics in the magnetic potential are perhaps hardly sufficiently well determined to bear the weight given them in this formula."

Irregularities in the structure of the earth's crust are not considered in making the calculations, yet these present contrasts in electrical conductivity which certainly distort the electric flow. Perhaps the most pronounced large-scale contrast of this nature is that between land and sea, the conductivity of sea-water being several orders of magnitude greater than that of land.[19] Other currents of more or less local extent and of quite different origin may at places be superimposed upon the more general system, thus adding to the complexity (see reference 15). Furthermore, one should not neglect to question the reliability of the earth-current data provided those data were obtained in such a way as to give no criteria by means of which it may be ascertained that extremely local phenomena, especially such as are produced by the method of measurement, have been eliminated. Such modifying influences may account for some of the disparities which have been noted. In any case, the induction theory is the only one now in sight that can claim attention.

One may therefore tentatively entertain the view that the earth-

[17a] Before sending this to press the values of these data were converted to conventional units on the basis of information found in a paper by von Stephan. Berlin. SitzBer. Ak. Wiss. No. 39: 553–561 (1886); see also O. H. GISH, Terr. Mag., **41**: 87–88 (1936). The Berlin data now appear to be only 13 per cent greater than those derived by CHAPMAN and WHITEHEAD.

[18] Calculations for Greenwich and Berlin are given in reference 15, those for Ebro by S. CHAPMAN and T. T. WHITEHEAD in Terr. Mag., **28**: 125–128 (1923), and those for Watheroo by GISH and ROONEY have not been published in detail.

[19] H. ERTEL gives a helpful theoretical discussion which takes account of contrasts in the electrical conductivity of the earth. Berlin, Veröff. Met. Inst., No. 391 (1932)

currents which are observed are in the main induced by magnetic variations, but that their strength and direction are modified in a manner which varies from place to place and which depends upon the distribution and configuration of oceans and continents as well as upon other structural features of the earth. Modifications produced in the earth-currents by the deep structure of the earth's crust may thus constitute electrical messages which contain information about conditions in that little-known region.

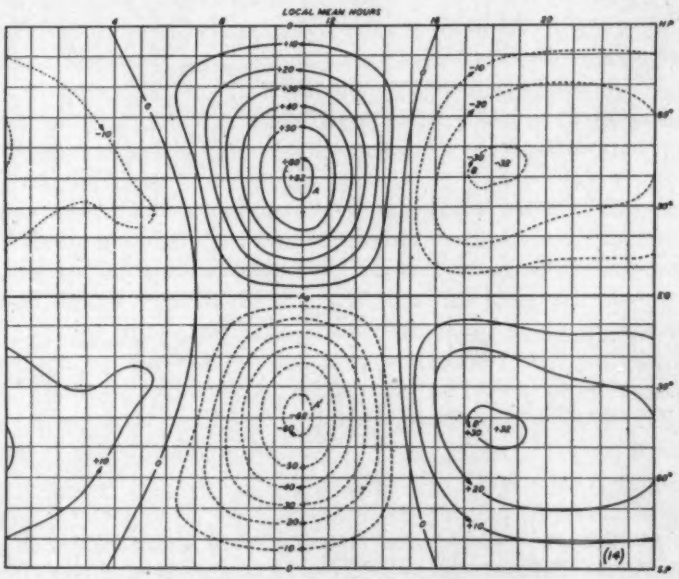
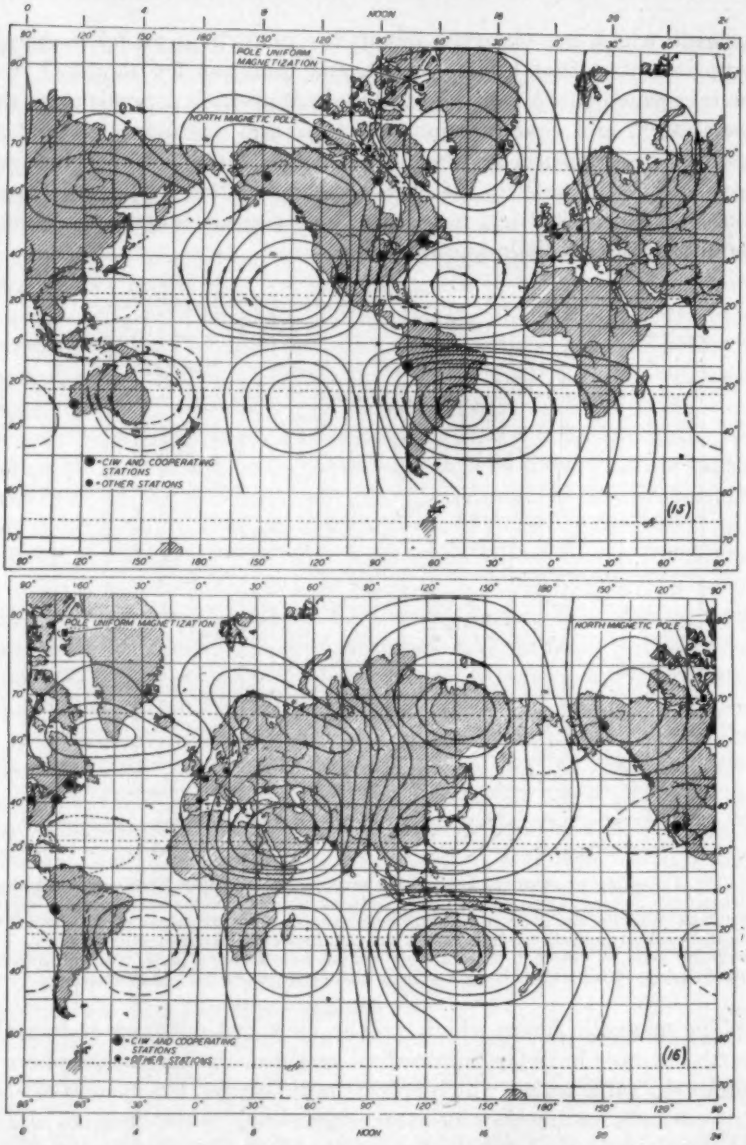


Fig. 14.—Electric currents beyond the stratosphere. Electric currents in the high atmosphere flowing in extensive eddies like those depicted in this world map by Bartels would account for the average tranquil diurnal-changes in terrestrial magnetism. This current-system is fixed relative to the sun and hence the earth rotates within it. The magnetic field of different parts of this system passes over a given place at different times of day, thus bringing a regular daily change in the earth's magnetism.

The magnetic forces which, on the view just outlined, induce the earth-currents have their immediate origin in the high atmosphere in about the same region which reflects radio waves. If a system of electric currents having the character represented by the diagram of Fig. 14 circulates in that region of the atmosphere, it would be capable of producing the daily magnetic changes which are observed at the surface of the earth. To justify the assumption that there exists such a system of currents or any equivalent which may produce the corre-

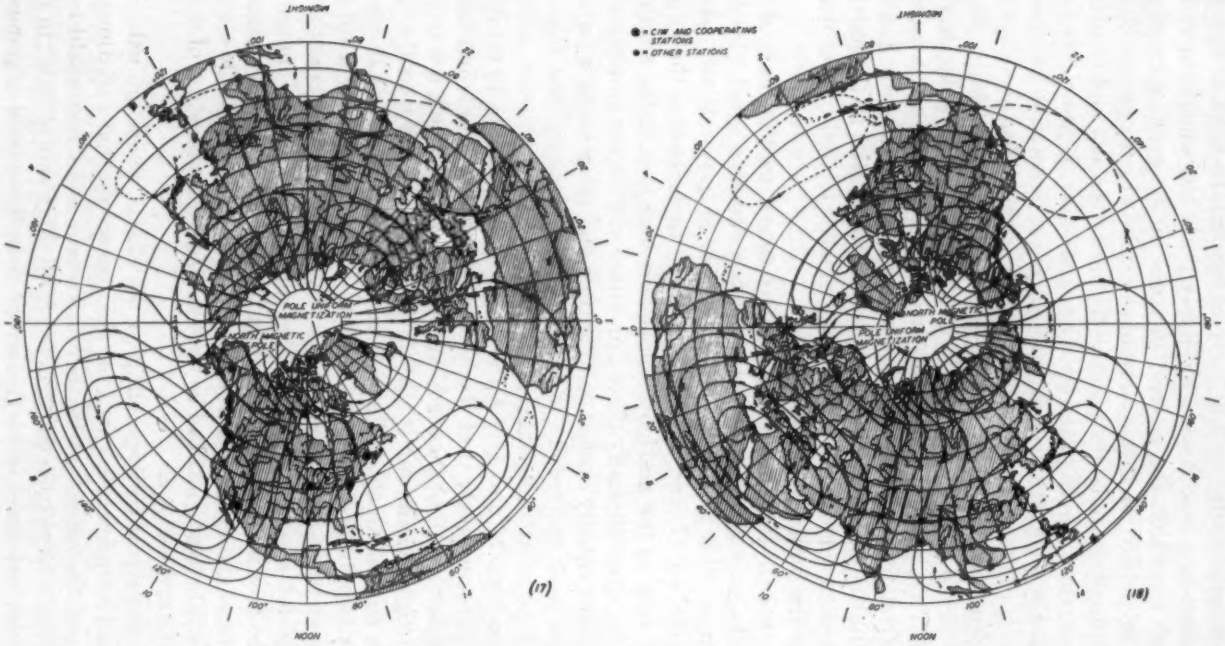


Figs. 15 and 16.—An interpretation: electrical eddies in the earth. The tranquil electric messages as interpreted here refer to electric currents which circulate in extensive eddies in the earth's crust. These, as viewed from the sun at about the time of the equinoxes, are shown here diagrammatically—(a) for daytime over the Western Hemisphere (Fig. 15) and (b) for daytime over the Eastern Hemisphere (Fig. 16).

sponding magnetic effect would carry us beyond the scope of this discussion, since it is here desired to simply point out somewhat of the mechanism by which the electric currents in the earth may be induced. The portion of this system of currents which appears at the center of the diagram is always directly under the sun and therefore the whole system moves relative to the earth, making a rotation once each day. The magnetic field of this electrical circulation as viewed from outside of the earth is one which in its principal features does not change appreciably with time, but, since it is moving relative to an observer on the earth, it appears to him to undergo a regular diurnal variation. This magnetic field, together with the earth which rotates within it, constitute the electric machine which generates the electric currents in the earth. Thus one might expect to find in the earth a general system of electrical circulations which is related to that represented for the higher atmosphere.

It has recently become possible to construct, on the basis of observed data, a world picture of the electric currents which circulate in the earth. This picture shows a number of great electric eddies (see Figs. 15, 16, 17, and 18). Eight of these are located in the middle latitudes, four in the northern hemisphere and four in the southern hemisphere, symmetrically placed on either side of the equator with centers about equally spaced in longitude and lying along a parallel of latitude near the tropics of Cancer and Capricorn (see Figs. 15 and 16). Four more such eddies with centers in the Arctic are also disclosed (see Figs. 17 and 18). Although there are no data to establish the fact, it seems likely that there are also four corresponding eddies in the Antarctic. All of these eddies follow the sun in such a way that there are eight on the sunlit side of the earth and eight on the dark side. The curves which outline the eddies are constructed in such a way that two adjacent curves indicate the boundaries of a tube of flow. Those tubes which are bounded by solid lines all contain the same amount of current except that in the case of the innermost curves the flow is sometimes less than that for a full tube. In order to show some of the weaker eddies it was necessary to subdivide some of the tubes. These are outlined by broken lines. The direction of flow is that of the arrows.

Current-systems corresponding to the charts which are exhibited here would completely account for the average diurnal variations observed in earth-currents at Watheroo, Tucson, and Chesterfield Inlet. Similar charts have been constructed from other sets of data; in fact, all the principal series of earth-current data have been examined in



Figs. 17 and 18.—The polar aspect. The eddies in the Northern Hemisphere—(a) for daytime in the Western Hemisphere (Fig. 17) and (b) for daytime in the Eastern Hemisphere (Fig. 18).

the same manner and without exception they are consistent with a scheme having the general features here depicted. In order that this picture may the better represent the observed facts, the tubes of flow must be regarded as very flexible, easily deformable, so that the shape of the tubes may be readily distorted and even the centers of the eddies displaced in such a way as to conform with the distribution of the electrical properties of the Earth, especially of that portion which constitutes the more immediate environment of a given eddy. It also seems likely that the development and the orientation of the eddies should be in some relation to the magnetic axis of the earth. When the general aspects of pertinent earth-current data are viewed in such a perspective they will, it is believed, be seen to be consistent with the principal features of the interpretation which the charts are designed to convey.

Returning again to an examination of the charts, it will be noticed that the current in the daylight eddies is considerably greater than that in the others; at least this is true for the eddies located in the middle latitudes. The centers of the forenoon eddies of the middle latitudes are approximately on the meridian for which the time of day is 9 a.m., while the afternoon eddies center on the meridian for which the time is about 3 p.m. Considerable flexibility must be allowed for this feature. The circulation in the forenoon eddy of the northern hemisphere and that in the afternoon eddy of the southern hemisphere are clockwise, whereas in the other two daylight eddies the circulation is counter-clockwise. A similar description applies to the nighttime eddies. The circulation in the eddies of the Arctic region is in the same sense as the corresponding eddies of the middle latitudes in the northern hemisphere. As these eddies move relative to the earth the direction and intensity of the earth-current at a given place change, those changes depending upon the position that place may occupy in the eddies and hence depending also upon the latitude of the place. This then is a world view of the gross aspects of the quiet-period earth-currents—the most comprehensive interpretation thus far made of the tranquil electric messages from the earth. It is, however, but a beginning; much deciphering remains yet to be done.

CHEMISTRY.—*Notes on the preparation and composition of wustite phases.*[1] E. E. WOOD and J. B. FERGUSON, University of Toronto.

[1] Received March 25, 1936.

THE DEHYDRATION OF FERROUS HYDROXIDE

Ralston (12) has suggested that ferrous hydroxide might be a suitable material from which to prepare ferrous oxide. Pure white ferrous hydroxide was prepared from aqueous solutions of ferrous sulphate and potassium hydroxide in an atmosphere of nitrogen. It was filtered, washed with water and then dehydrated in vacuo, the whole operation being conducted in a closed apparatus. Great care was taken to exclude extraneous oxygen and the ferrous sulphate solution was prepared by the method of Benson (2). The relative amounts of ferrous and total iron were determined on the same sample without weighing by the electrometric method of Hostetter and Roberts (8).

The dehydration experiments were made at temperatures ranging from 100 to 180°C. and for periods of time varying from 95 minutes to 7.5 hours. We considered the reaction velocity too small at temperatures below 100°C. to warrant work at lower temperatures. The final products always contained ferric iron which was larger the higher the temperature of dehydration. It also increased with time up to a certain point and then remained constant at constant temperature as though the oxidation were directly related to the production of water vapour which was removed by a suitably protected vacuum pump.

Welo and Baudisch (13) seem inclined to attribute the formation of ferric iron, at least in part, to the decomposition of ferrous oxide to form magnetite and iron. We found no trace of gas when a sample was dissolved in acid and doubt if free iron were present in our products and would prefer to regard a wustite as a primary product. Since our most reduced materials only contained 80.4 percent ferrous oxide, this method of preparation is no better than many others and the technique is very much more difficult.

THE DECOMPOSITION OF FERROUS OXALATE

Andrew, Maddocks and Howatt (1) claim to have prepared ferrous oxide, 99.5 percent pure or better, by heating the oxalate in vacuo at the proper temperature. Jette and Foote (9) were unable to duplicate their work. We made a number of experiments and although we varied our procedures in many ways, we were also unable to duplicate the work of the former.

One of the stumbling blocks in such work is the analytical method and Andrew et al. may not have obtained the pure ferrous oxide which their analytical results seem to indicate. But the work of Jette and Foote and of ourselves shows that their method is not a procedure for

the preparation of pure ferrous oxide which can be employed with any reasonable assurance of the production of a pure oxide.

THE REACTION BETWEEN IRON AND MAGNETITE

The early observations of Chaudron (4) indicated that iron and magnetite, formed as decomposition products of wustite, would readily re-combine at higher temperatures. Mulligan (6a) also observed in our laboratory a similar re-combination. But the later work of Chaudron and Forestier (5), as Ralston (12) points out, does not seem to confirm these observations.

In order to be sure that our results might not be determined by a particular wustite sample, we selected a number of materials which differed in preparation and composition for this study. The total and free iron values for these were respectively as follows: A, 75.8 and 0.26; B, 79.2 and 9.1; C, 77.4 and 5.1; and D, 78.7 and 9.5 percentages respectively. These samples were sealed in Pyrex glass tubes in vacuo and heated for five hours at 515°C. (*D*, decomposed) or for five hours at 610°C. (*R* re-combined). The tubes were removed from the furnace and chilled as rapidly as possible. The products were analysed by the electrometric method for total iron using potassium dichromate and by the mercuric chloride method (7) for free iron. Mulligan had previously used the copper sulphate method for free iron. The results are given in Table 1. There are certain irregularities in this table. The

TABLE 1.—THE FREE IRON CONTENT OF HEAT-TREATED WUSTITE.

SAMPLE.	A.	B.	C.	D.
	weight percent			
Initial	0.26	9.1	5.1	9.5
D	12.0	23.65	13.75	20.75
R	0.1	10.2	5.3	7.8
D	8.9	16.4	7.9	11.2
R	0.35	9.1	1.4	6.1

second decomposition and re-combination did not yield the same products as the first. In C and D, the final products contained less free iron than the original materials showing that some of the magnetite and iron formed during the original preparations of these samples had also re-combined. But there is ample evidence that the re-combination of such iron and magnetite is easily obtained and the earlier observations are thus confirmed.

The further question, whether or not iron and magnetite from extraneous sources will readily combine, was also investigated. A finely

ground electrolytic iron and a sample of Kahlbaum's magnetite were selected for this study. The former had been reduced in hydrogen at 800–900°C. and was originally from 100 to 200 mesh material. The latter was an extremely fine powder containing 24.07 percent of iron in the ferrous condition, the theoretical value being 24.12. Various mixtures were heated in vacuo in sealed Pyrex glass or silica glass containers which were removed from the furnace and quenched as rapidly as the containers would permit without breakage. Gas usually formed from the charge in the initial heat treatment and a slight oxidation occurred. We attributed this to air adsorbed on the fine magnetite powder. Because of this gas production and oxidation, the composition of the charge was adjusted by the addition of free iron after this first treatment in cases in which a definite total composition was required. The samples were also ground in an agate mortar in nitrogen between heat treatments in order to uncover residual iron and also prior to analysis and to magnetic separation when this was made. In some experiments with silica tubes, it was found advisable to hold the charge in a container of black sheet iron inside the silica tube to prevent contamination by flakes of silica when the charge was quenched.

Complete combination was not observed in samples high in iron. A sample which initially contained 19.4_2 percent free iron contained 1.63 percent after a heat treatment of 7.75 hours at 691°C. Complete combination was obtained at 1097 ± 10°C. with samples which initially contained 10.9_7 and 8.4_7 percent free iron respectively, and with the former sample (10.97) at 926 ± 3°C. A serious attempt was made to prepare pure ferrous oxide by the complete combination of iron and magnetite in the proper proportions but without success, the products always containing free iron and ferric iron. Since pure ferrous oxide could not be prepared in this manner, attempts were made to find the limits of the wustite field, next to iron, on the iron-oxygen diagram through the use of samples containing initially an excess of iron. The final products were separated by means of a strong electromagnet. A sample which contained initially 80.1 percent total iron was heated for 8.5 hours at 683°C., 5.5 hours at 693°C. and 6 hours at 703°C. The non-magnetic portion contained no detectable free iron, 77.0_3 percent total iron and 70.6_6 percent iron in the ferrous condition. This result agrees fairly well with the value of 76.9 given by Pfeil (11) and also with the value indicated for this temperature on the diagram given by Mathewson, Spire and Milligan (10). Pfeil indicates a vertical boundary line at 76.9 percent and Jette and Foote (9)

found evidence of free iron in samples containing 77.4 percent iron which had been heated respectively at 600, 795, 915 and 1035°C. From the ferrous iron content of samples prepared by us at 1097 and 926°C. we obtained points at 77.0_5 and 76.9 percent total iron which would agree with Pfeil's observations. Since the invariant point, Fe + liquid⇄wustite at 1380°C. determined by Bowen and Schairer (3), lies at 76.8_3 percent total iron, the boundary line, if vertical in the upper range, must lie nearer iron than this percentage.

Additional experiments at 727°C. indicated that the wustite field extends, at this temperature toward magnetite to at least 76.0 percent total iron and probably as far as 75.2 percent. Since the weight of evidence at present available seems to favour the opinion that pure ferrous oxide is unstable at and below the invariant point at 1380°C. and observers have disagreed upon the exact extent of the wustite field, the question as to whether or not the most stable wustite was obtained in many experiments is a pertinent one. It was our reference (6) to such wustites which has been misinterpreted by Ralston (12) to mean different allotropic forms of ferrous oxide.[2] But there can be no doubt that in many cases unstable wustites must have been formed if the compositions which have been reported can be considered at all reliable. We cannot say that our wustites were the most stable solutions, we can only say that, with this new procedure, we have been able to prepare products which compare favorably with those produced by other methods and that the procedure is relatively simple and convenient.

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[2] Misquotation admitted in private communication.

ZOOLOGY.—*Echinoderms collected by Capt. Robert A. Bartlett in the seas about Baffin Land and Greenland.*[1] AUSTIN H. CLARK, U. S. National Museum.

Capt. Robert A. Bartlett's investigations of the waters about Baffin Land and Greenland carried on during the past few years have resulted in bringing together a noteworthy collection of echinoderms which greatly increases our knowledge of the distribution of these animals in that section of the Arctic.

Especially noteworthy are the records from no less than eleven stations south and west of Baffin Land, previously unknown territory so far as the echinoderms are concerned. Scarcely less interesting are the records from northwestern and eastern Greenland, regions where, because of the formidable difficulties to be overcome, little collecting ever has been done.

The localities at which he collected echinoderms were the following:

LABRADOR: 1. Saglak Harbour.

WEST GREENLAND: 2. Disko Island. 3. Northwest of Upernivik (lat. 74° 21′ N., long. 60° 30′ W.).

BAFFIN LAND AND VICINITY: 4. Three miles south of Salisbury Island, Hudson Strait. 5. Fox Channel. 6. Fox Channel (lat. 66° 30′ N., long. 80° W.). 7. Fox Channel (lat. 66° 43′ N., long. 80° 07′ W.). 8. Southern part of Fox Basin. 9. Fox Basin. 10. Center of Fox Basin. 11. Off the northwestern end of Vansittart Island, Frozen Strait, north of Southampton Island. 12. Sturgis Bourne Strait, eastern end of Hurd Channel, Melville Peninsula. 13. Duckett's Cove, Hurd Channel. 14. South of Cape Martineau, Melville Peninsula. 15. Off Cobourg Island, northwestern Baffin Bay (lat. 75° 40′ N., long. 78° 40′ W.). 16. Off the eastern end of Cobourg Island (lat. 75° 40′ N., long. 78° 50′ W.). 17. Off the eastern end of Cobourg Island (lat. 75° 40′ N., long. 78° 53′ W.). 18. Off the eastern end of Cobourg Island. 19. Off the eastern end of Cobourg Island (lat. 75° 40′ N., long. 78° 55′ W.). 20. Off the eastern end of Cobourg Island (lat. 75° 40′ N., long. 78° 56′ W.). 21. Off the southern end of Cobourg Island (lat. 75° 40′ N., long. 78° 58′ W.).

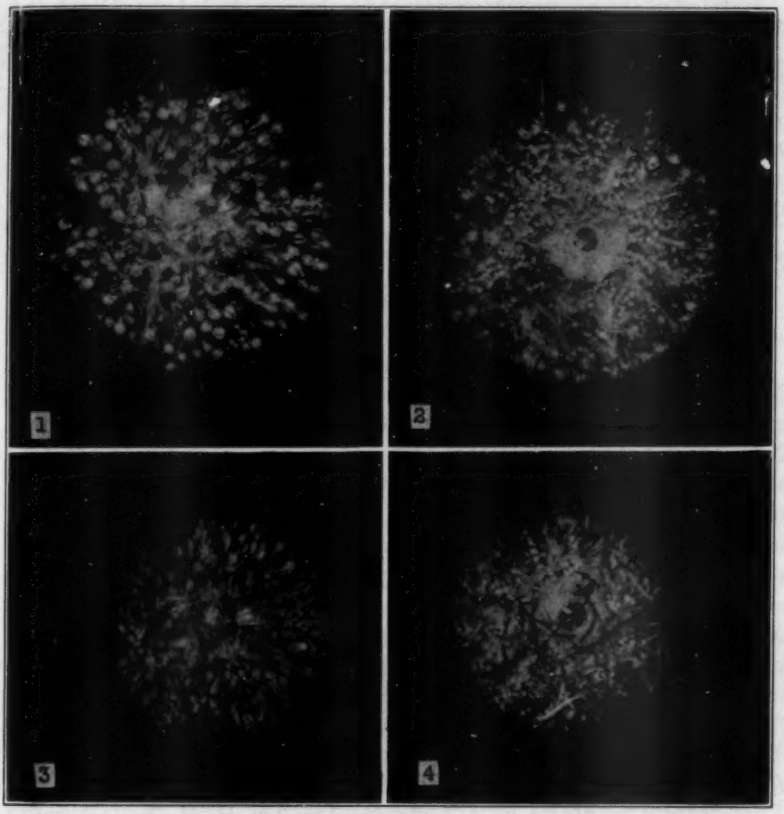
NORTH GREENLAND: 22. Cape York. 23. Kerkotak, Salvo Island, Melville Bay, just east of Cape York. 24. Thule, North Star Bay, north of Cape York. 25. North Star Bay. 26. Parker Snow Bay (lat. 76° 07′ N., long. 68° 20′ W.). 27. Parker Snow Bay. 28. Saunders Island, Westenholm Sound. 29. Off Dalrimple Rock, Westenholm Sound. 30. Five miles south of Cape Chalon, Westenholm Sound. 31. Herbert Island, Whale Sound. 32. Northumberland Island, Murchison Sound. 33. Murchison Sound. 34. Inglefield Gulf. 35. Karnah, Inglefield Gulf. 36. Nerke, near Morris Jessup glacier. 37. Cape Alexander, Smith Sound.

EAST GREENLAND: 38. Angmagsalik. 39. Between Greenland and Jan Mayen (lat. 72° 21′ N., long. 16° 30′ W.). 40. East of Scoresby Sound (lat. 70° 21′ N., long. 16° 30′ W.); 110 fathoms. 41. Off Wollaston Foreland

[1] Published with the permission of the Secretary of the Smithsonian Institution. Received March 10, 1936.

(lat. 74° 04′ N., long. 17° 58′ W.). 42. Off Wollaston Foreland (lat. 74° 20′ N., long. 16° 30′ W.). 43. Clavering Island.

The species collected by Captain Bartlett (exclusive of the holo-



Figs. 1–4.—*Strongylocentrotus dröbachiensis*, two young specimens with the test about 17 mm (Figs. 1, 2) and 13 mm (Figs. 3, 4) in horizontal diameter, aboral (Figs. 1, 3) and oral (Figs. 2, 4) views. Collected by Capt. R. A. Bartlett on the west side of Clavering Island, east Greenland, in 50-15 fathoms, on August 3, 1930.

thurians) were the following. The numbers refer to the localities listed above:

ASTEROIDEA: *Crossaster papposus*, 6, 8, 9, 13, 16, 18. *Henricia sanguinolenta*, 9, 10, 40, 43. *Pteraster militaris*, 9, 10, 43. *Stephanasterias albula*, 9, 10, 14, 18, 24, 28, 31, 32, 34, 35, 37, 38. *Leptasterias polaris*, 4, 43. *Leptasterias groenlandica*, 4, 18, 24, 30, 31, 32, 35, 37, 43.

OPHIUROIDEA: *Ophiacantha bidentata*, 1, 3, 5, 6, 8, 9, 10, 12, 13, 14,

15, 16, 30, 31, 34, 40, 43. *Ophiopus arcticus*, 6, 10, 39, 43. *Amphiura sundevalli*, 43. *Ophiopholis aculeata*, 4, 15, 16, 26. *Ophiocten sericeum*, 13, 15, 17, 19, 22, 25, 28, 32, 36, 38, 43. *Ophiura robusta*, 5, 6, 7, 8, 9, 10, 14, 15, 16, 19, 21, 25, 28, 30, 32, 37, 43. *Ophiura sarsii*, 17, 22, 25, 27, 28, 34, 36, 37. *Stegophiura nodosa*, 13, 22, 29, 43.

ECHINOIDEA: *Strongylocentrotus dröbachiensis*, 1, 2, 4, 10, 11, 16, 20, 21, 22, 23, 25, 28, 29, 30, 32, 37, 40, 41, 42, 43.

CRINOIDEA: *Heliometra glacialis*, 4, 10, 16, 17, 32, 33, 43. *Poliometra prolixa*, 40, 41.

Note.—Worthy of special mention are two small specimens of *Strongylocentrotus dröbachiensis* (Figs. 1–4) from Clavering Island on which, on the aboral surface, the pedicellariae are so very numerous as to be more conspicuous than the spines.

ZOOLOGY.—*A new pocket gopher from New Mexico.*[1] E. RAYMOND HALL, University of California. (Communicated by E. A. GOLDMAN.)

In the spring of 1935 Miss Annie M. Alexander accompanied by Miss Louise Kellogg collected for the Museum of Vertebrate Zoology a series of *Thomomys* from the Rio Grande Valley near Albuquerque, New Mexico. Specimens from this general region had been referred to *Thomomys aureus* Allen, but this was at a time when that name was used in a more inclusive sense than it is at present. It was, therefore, no surprise to find that the gopher from Albuquerque could not be referred to *aureus;* indeed it was knowledge of this probability and curiosity as to the true identity of the pocket gopher there which led Miss Alexander to make special effort to obtain the specimens. Comparisons reveal that the animal from Albuquerque pertains to an unnamed race which is larger, and different in other respects, from *fulvus*, *tularosae*, *pervagus*, *opulentus* and *aureus*, the subspecies of *Thomomys bottae* (see Goldman)[2] whose ranges adjoin that of the new form. For the privilege of making direct comparisons with *opulentus* I am obliged to Major E. A. Goldman and Dr. H. H. T. Jackson of the United States Bureau of Biological Survey. To Dr. H. E. Anthony of the American Museum of Natural History I am similarly obliged for lending the original series used in naming *Thomomys toltecus*.

Thomomys bottae connectens, new subspecies

Type.—Male, adult, skull and skin; no. 66627, Mus. Vert. Zool.; Clawson Dairy, 5 miles north of Albuquerque, 4,943 feet elevation, Bernalillo County, New Mexico; May 6, 1935; collected by Annie M. Alexander, original no. 2981.

[1] Received January 3, 1936.

[2] Proc. Biol. Soc. Washington **48**: 135, 150. 1935.

Range.—Valley of the Rio Grande in central New Mexico, probably from northern Socorro County northward to Bernalillo.

Diagnosis.—Size: Large (see measurements). Color: In fresh summer pelage cinnamon buff (color terms after Ridgway)[3]; whitish below with plumbeous areas and with cinnamon buff extending onto pectoral region, and sometimes to other sections of the underparts; insides of cheek pouches and usually nose, blackish; postauricular patches small. Winter pelage with a reduced amount of cinnamon buff on the upper parts producing a "gray" coat. Skull: Large; rostrum broad and its length amounting to more than 67 percent of zygomatic breadth; nasals posteriorly truncate; hamulus of lacrimal large; interpterygoid space V-shaped and provided with median spine.

TABLE 1.—MEASUREMENTS IN MILLIMETERS OF ADULT TOPOTYPES AND TYPES OF T. B. CONNECTENS AND T. B. TOLTECUS

Catalogue number	*Connectens*								*Toltecus*		
	66638	66642	66635	66636	66634	66627	66628	Average	5440 — 4305	5386 — 4304	Average
Sex	♀	♀	♂	♂	♂	♂	♂	♂	♂	♂	♂
Total length	240	232	257	270	267	256	256	261	—	—	—
Length of tail	72	66	76	73	74	68	70	72	—	—	—
Length of hind foot	32	31	36	35	35	35	35	35	29[b]	27[b]	28[b]
Basilar length	37.2	35.5[a]	44.5[a]	42.5	41.1	42.7	40.0	42.2	37.5	38.2[a]	37.9
Length of nasals	14.7	13.5	17.8	17.4	16.7	17.0	16.8	17.1	14.2	14.8	14.5
Zygomatic breadth	25.3	25.4	31.0[a]	31.1	30.3	29.5	—	30.5	28.2	28.7	28.5
Mastoid breadth	20.9	20.9	25.5	24.3	24.5	23.7	22.8	24.2	21.6	23.8[a]	22.7
Breadth of rostrum	8.8	7.2	11.1	10.2	11.0	10.3	10.0	10.5	8.4	9.1	8.8
Interorbital constriction	6.9	7.2	7.2	7.2	7.4	7.3	7.7	7.4	6.7	6.5	6.6
Maxillary tooth-row	9.1	8.3	9.8	9.4	9.1	9.4	9.3	9.4	8.5	8.0	8.3
Extension of premaxillae posteriorly to nasals	2.1	2.9	2.2	2.2	3.3	3.2	2.6	2.7	3.3	3.4	3.4
Depth of skull	16.3	15.5	19.0	17.9	18.3	18.0	17.3	18.1	15.9	16.6	16.3
Length of rostrum[c]	17.7	16.9	21.8	21.7	24.4	21.2	19.7	21.8	18.0	17.5	17.8

[a] Estimated.
[b] Measured from the dried skin.
[c] Measured between the anterior border of the nasals and the maxilla at the lateral end of the hamulus of the lacrimal.

Comparisons.—Compared with *Thomomys bottae aureus, connectens* is larger in external measurements, darker colored above, and below has the pectoral region strongly marked with cinnamon buff rather than white, and it is larger in every cranial measurement taken. The interpterygoid space is V-shaped rather than U-shaped; the exoccipital extends farther laterally, revealing an inverted V-shaped rather than inverted U-shaped, face of the mastoid portion of the auditory bulla; the rostrum, relative to the basilar length, is longer and wider; and the skull is more than a fourth heavier as shown by the crania of adult males without lower jaws which average 4.66 grams as against 3.33 grams.

Compared with specimens of *Thomomys bottae opulentus* from Las Cruces (1), Garfield (5), Las Palomas (1) and San Marcial (6), *T. b. connectens* is slightly less reddish above and especially below, is larger in external and cranial measurements—in many parts of the skull constantly so. The skull of *connectens* is by actual weight much heavier: males average 4.6 grams as against 2.5 and females average 2.6 grams as opposed to 1.9. In *connectens* the premaxillae extend farther behind the nasals, the external meatus is prolonged into a distinct tube, the temporal ridges approach one another more closely, the hamulus of each lacrimal bone is as large again, the exoccipital

[3] Color standards and color nomenclature. Washington, D. C. 1912.

extends farther laterally revealing less of the mastoid portion of the auditory bulla, and the skull is generally more angular with better developed processes and ridges marking areas of muscle attachment.

Compared with 5 topotypes and the type of *Thomomys bottae toltecus*, *T. b. connectens* is slightly lighter colored, has much longer hind feet (on dry skins, adult males measure 33 mm. as against 29 mm.) and is constantly larger in every part measured, except for the mastoid breadth and extension of the premaxillae posteriorly to the nasals. In the two parts of the skull indicated there is a slight overlap in measurements. Relative to the basilar length each of the five adult males of *connectens* has longer nasals and rostrum, broader rostrum and a lesser width across the zygomatic arches than has either of the two adult males of *toltecus*. In *connectens* the length of the rostrum amounts to more, rather than less, than 67 percent of the zygomatic breadth. Also, in *connectens* the hamulus of each lacrimal bone is as large again and the inferior margin of the anterior opening of the infraorbital canal is continued anteriorly as a distinct ridge rather than curved upward to form part of an ellipse. Measurements, for the most part not previously available, for *toltecus* are offered above as facilitating comparison with related races.

Remarks.—Among named subspecies of *T. b. bottae* whose ranges approach nearest to that of *connectens*, probably greatest similarity is shown to *T. b. aureus*. The range of *connectens*, as known to me, however, is separated from that of *aureus* by a large area from which no specimens have been examined though the species *T. bottae* doubtless occurs in suitable environments there. The northwestern limits of range of *connectens*, then, remain to be determined. Specimens from Socorro are variously intermediate in color and to a certain extent in external measurements between *connectens* and *opulentus* but cranially they agree well with the latter.

Specimens examined.—Total number, 19 as follows: Type locality, 14; 4.5 miles south Albuquerque, 4,943 feet elevation, Bernalillo County, New Mexico, 4.

ZOOLOGY.—*A note on* Dictyocaulus *from domestic and wild ruminants.*[1] G. DIKMANS, Zoological Division, Bureau of Animal Industry. (Communicated by MAURICE C. HALL.)

Chapin (1925) described as *Dictyocaulus hadweni* n. sp. a nematode collected from the lungs of the American bison, *Bison bison*, at Wainright, Alberta, Canada, by Dr. Seymour Hadwen. Following the description, Chapin devoted a short paragraph to a comparison of *D. hadweni* with *D. filaria*, and differentiated *D. hadweni* from *D. filaria* by the more abrupt termination of the dorsal rays, the complete fusion of the medio-lateral and postero-lateral rays, and the longer spicules. Apparently the use of the name *Dictyocaulus filaria* should be considered as a *lapsus calami* for *Dictyocaulus viviparus*, or else Chapin really intended to compare *D. hadweni* with *D. filaria*. *D.*

[1] Received March 17, 1936.

hadweni resembles *D. viviparus* in the characters mentioned by the author and there would, therefore, have been some reason for attempting to differentiate between them, but *D. filaria* differs so markedly from *D. hadweni* in the conformation and size of the spicules alone that comparisons on any points other than spicules would be the only ones in order. Chapin stated that *D. hadweni* differs from *D. filaria* "in the longer spicules," and from this statement the reader would infer that the spicules of *D. hadweni* are longer than those of *D. filaria* whereas, as a matter of fact, the spicules of *D. hadweni* are shorter than those of *D. filaria*. Since this fact could not have escaped

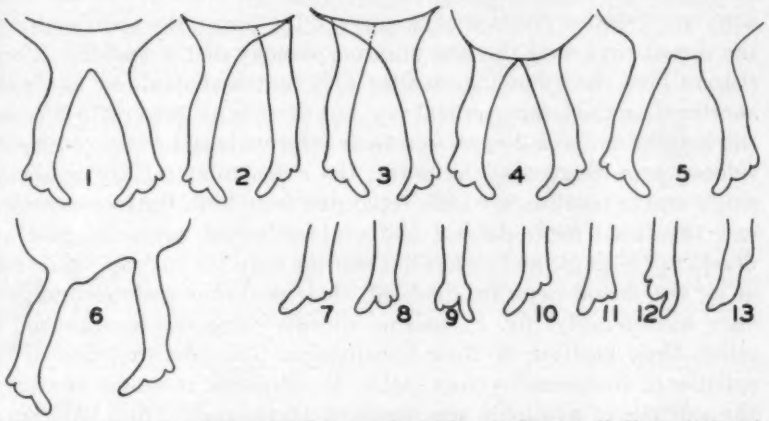


FIG. 1.—Dorsal rays of bursa of *Dictyocaulus viviparus* showing (1–6), variations in position and, (7–13), variations in termination.

Chapin's attention if he had made a comparative study of these two nematodes, it might be inferred that the use of the name *D. filaria* was actually a *lapsus calami*. However, this inference also meets with difficulties because had the author intended to compare *D. hadweni* with *D. viviparus* and had he made a comparative study of these two forms he would have noted their similarity in the very points on which he attempted to differentiate them, viz., the fusion of the mediolateral and postero-lateral rays, the position and termination of the dorsal rays, and the conformation of the spicules, the spicules of *D. hadweni* differing from the spicules of *D. viviparus* in size only.

For some time the writer has been making all identifications of lungworms from domestic and wild ruminants as these have been referred to the Zoological Division for determination, and during that time considerable difficulty has been experienced in differentiating *D.*

hadweni from *D. viviparus* on any valid morphological grounds. Dr. W. E. Swales of the Institute of Parasitology, McDonald College, Quebec, Canada, under a coöperative agreement for exchange of specimens in various parasite groups, has referred specimens of *Dictyocaulus* collected from cattle and various wild ruminants in Canada to the Zoological Division of the Bureau of Animal Industry for study.

Since the females of species of *Dictyocaulus* are, for all practical purposes, indistinguishable, the writer has based his study of the members of the genus occurring in ruminants in North America on a comparison of male specimens, with special reference to the character and relative position of the rays of the bursa, the termination of the dorsal rays, and the size and morphology of the spicules. These studies give the following results: The ventro-ventral ray is always shorter than the latero-ventral ray, but there is no fixed ratio between the lengths of these 2 rays, and their relative lengths cannot be considered as a diagnostic character; the externo-lateral ray is always single and in position is widely separated from both the latero-ventral and the fused medio-lateral and postero-lateral rays; the externo-dorsal ray is single and somewhat shorter than the rays on either side of it; the dorsal rays are doubled, their positions and terminations vary considerably (fig. 1), and no specific value can be attached to either their position or their termination. The conformation of the spicules of *Dictyocaulus* from cattle, *D. viviparus*, is similar to that of the spicules of available specimens of *Dictyocaulus* from wild ruminants. In general the spicules of *Dictyocaulus* from wild ruminants are somewhat longer than the spicules of *D. viviparus* from cattle, but there is considerable overlapping (table 1).

So far as the females of *D. hadweni* and *D. viviparus* are concerned there are no definite morphological characters on which they can be separated from each other. It appears, therefore, that *D. hadweni* cannot be separated from *D. viviparus* on any valid, morphological grounds and, since *D. viviparus* is the older name, *D. hadweni* must fall into synonymy so far as its morphology is concerned. Only carefully controlled feeding experiments could establish whether we are dealing with biological varieties capable of infecting only cattle or only deer or whether these nematodes are biologically as well as morphologically identical.

Hsü (1935) described as *Dictyocaulus khawi* a nematode stated to have been collected from the lungs of swine in Tonkin, French Indo-China. The only point in which this nematode is said to differ from

D. viviparus is that one of the 3 digitations of the dorsal ray has an externo-lateral position. In view of the fact that the terminations of the dorsal rays may be extremely variable in position and appearance (fig. 1) this minor difference does not appear to be sufficient for the creation of a new species. On morphological grounds, therefore, *Dictyocaulus khawi* would also be considered as a synonym of *Dictyocaulus viviparus*, but in view of the fact that over most of the world *Dictyocaulus* is not found in pigs in spite of evident opportunities for

TABLE 1.—LENGTH OF SPICULES OF DICTYOCAULUS VIVIPARUS COLLECTED FROM DIFFERENT HOSTS

Hosts	No. of male specimens examined	Minimum length of spicules in microns	Maximum length of spicules in microns
Cattle *Bos taurus*	29	220	255
American bison *Bison bison*	14	220	295
Moose *Alces americana*	1	255	255
Elk *Cervus canadensis*	10	255	325
Reindeer *Rangifer tarandus*	12	220	315
Black-tailed deer *Odocoileus columbianus*	3	235	300
White-tailed deer *Odocoileus virginianus*	4	176	220
Mule deer *Odocoileus hemionus*	3	220	220
Red deer, probably *Cervus canadensis*	4	255	295

infection from cattle, there is the possibility that under special conditions existing in French Indo-China a strain of *D. viviparus* has become adapted to swine, as *Necator americanus* of man appears to have become adapted to swine in the West Indies, with the development of a new biological species which may show, as does *N. suillus*, certain fixed morphological characters, however slight, differentiating it from the parent species. Since Hsü did not collect the specimens which he describes there is, of course, also the possibility of error in labelling to be considered.

Skrjabin (1931) described as *Dictyocaulus eckerti* a worm found in the lungs of reindeer in the U.S.S.R. He stated that this worm differs from *D. viviparus* as follows: *a*, In the presence of cervical papillae

(these are not mentioned in the part of the paper describing the nematode); *b*, in the presence of a mouth capsule; *c*, in the length of the spicules; *d*, in the structure of the terminal portion of the dorsal ray. The length of the spicules is given as 290 to 310μ and the figures accompanying the description show that they are morphologically similar to the spicules found in *D. viviparus*. The figure of the bursa of *D. eckerti* shows that the termination of the dorsal rays is similar to that of *D. viviparus*. With reference to the presence of a mouth capsule, the presence of a small, shallow, mouth capsule is a character of the genus and an examination of a number of specimens of *D. viviparus* collected from cattle at Bethesda, Md., shows that this character is present in *D. viviparus* from cattle as well as in *D. eckerti* from reindeer in the U.S.S.R. With reference to the presence of cervical papillae in *D. eckerti*, there appears to be no other record of the presence of these structures in members of the genus *Dictyocaulus*, and a careful examination of a number of specimens from both cattle and reindeer failed to reveal their presence. No information is furnished as to the appearance and location of the cervical papillae in *D. eckerti*. From Skrjabin's description and from the figures accompanying it, it appears that the lungworm collected from reindeer in the U.S.S.R. does not differ materially from *Dictyocaulus* collected from the lungs of reindeer in Alaska, aside from the rather surprising occurrence of cervical papillae in the former, and aside from this one item *D. eckerti* appears to be identical with *D. viviparus*.

DICTYOCAULUS VIVIPARUS (Bloch, 1782) Railliet and Henry, 1907

Synonyms.—*Gordius viviparus* Bloch, 1782; *Ascaris vituli* Bruguière, 1791; *Strongylus vitulorum* Rudolphi, 1809; *Strongylus micrurus* Mehlis, 1831; *Dictyocaulus hadweni* Chapin, 1925; (?) *Dictyocaulus eckerti* Skrjabin, 1931; (?) *Dictyocaulus khawi* Hsû, 1935.

Hosts.—Cattle, *Bos taurus;* American bison *Bison bison;* Moose, *Alces americana;* Elk, *Cervus canadensis;* Reindeer, *Rangifer tarandus;* Black-tailed deer, *Odocoileus columbianus;* white-tailed deer, *Odocoileus virginianus;* Mule deer, *Odocoileus hemionus;* Red deer, probably *Cervus canadensis;* (?) Swine, *Sus scrofa domestica.*

DICTYOCAULUS FILARIA (Rudolphi, 1809) Railliet and Henry, 1907

Dictyocaulus filaria is the common lungworm of sheep in North America, and has been collected also from the black-tailed deer, *Odocoileus columbianus*, and from the white-tailed deer, *Odocoileus virginianus*. In 24 male specimens from both deer and sheep, the length of the spicules varied from 330 to 580μ, spicules 330μ long and 580μ long each being found once and the lengths of all other spicules varying from 365 to 515μ. The ventro-ventral ray was found to be shorter than the latero-ventral ray in all the specimens

examined. The dorsal rays terminate in 3 processes but the position of these processes varies to such an extent that no diagnostic significance can be attached to it.

Bhalerao (1932) described as *Dictyocaulus unequalis* a nematode collected from the large bronchi of a Tibetan sheep. He stated that this nematode differs from *Dictyocaulus filaria* in having shorter spicules, only one male 28 mm long, with spicules 280 to 290μ long, being available for examination, and also in that the ventro-ventral ray of the bursa was shorter than the latero-ventral ray, and he gave the specific name *unequalis* because of this inequality of the ventral rays. Since the ventro-ventral ray in *Dictyocaulus* is usually shorter than the latero-ventral ray, this supposed difference between *D. filaria* and *D. unequalis* disappears and, in the absence of any noticeable morphological difference, the difference of 40 to 50 microns in length in spicules based on the examination of a single specimen does not appear to be sufficient reason for the making of a new species when an otherwise identical species has a range of 250 microns. *Dictyocaulus unequalis* is, therefore, considered as probably a synonym of *D. filaria*.

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BOTANY.—Eriogonum intrafractum, *a new species and new subgenus from Death Valley, California.*[1]

FREDERICK V. COVILLE AND C. V. MORTON, U. S. National Museum.

In the spring of 1932 the senior author and Mr. M. French Gilman, while studying the flora of Death Valley, California, under the auspices of the National Geographic Society, found a peculiar-looking perennial species of *Eriogonum*, which because of its immaturity remained unnamed. The plants were found in Titus Canyon, Grapevine Mountains, six miles below Leadfield, at an altitude of about 2,000 feet, growing in the crevices of a blue limestone ledge sloping to the north. The dead stems of the preceding year were about three feet high. Mr. Gilman revisited the locality and obtained additional specimens in 1934. These also were immature, and it was not until October, 1935, that Mr. Gilman was able to obtain good material,

[1] Published by permission of the Secretary of the Smithsonian Institution. Received February 26, 1936.

this indicating at once a new species which can not be referred to any of the recognized subgenera of *Eriogonum*. The new subgenus described below must therefore be added to the already rather long list of plants endemic to this peculiar region.

Eriogonum subgenus **Clastomyelon**[2] Coville & Morton, subg. nov.

Herbae perennes, caulibus erectis, altis, infra inflorescentiam non ramosis, fistulosis, demum interne transverse articulatis; folia radicalia, longepetiolata, pilosa; involucra sessilia, in verticillis disposita, late campanulata, non angulata, mox fissa et explanata, bracteolis nonnullis suffulta; bracteolae involucrorum saepe virides, crassae; pedicelli florum pubescentes; fructus basi bulboso-expansus, perspicue 3-cristatus, medio abrupte contractus.

TYPE SPECIES: *Eriogonum intrafractum* Coville & Morton.

Three subgenera of *Eriogonum* have commonly been recognized, namely, *Ganysma*, *Oregonium*, and *Eueriogonum*, from all of which the new subgenus *Clastomyelon* differs in the following characters:

1. *Articulate stems.* The main stem (which is erect, leafless, and unbranched) is divided into many transverse articulations. These, averaging about 5 mm in length, do not become obvious until the plant is past maturity, at which time they are easily visible as undulations beneath the outer stem covering. The latter at length weathers into shreds, and the moniliform articulations fall off one by one. Concerning this feature M. Gilman wrote: "When examining the Eriogonums notice the very peculiar structure of the larger parts of the stalks. Under the bark the stems are made up of little rings from one-fourth to three-fourths inch long. When old the bark falls away, leaving the stems made up of a series of white sections or joints looking like tiny napkin rings. The rings easily unjoint when weathered enough, and on the ground around old plants the fallen stems indicate the vintages of the different years' growth of stalks." These facts are obvious on several of the herbarium specimens cited.

2. *Whorled involucres.* Except on the ultimate branches of the stem the involucres are sessile and borne in whorls. They are usually three in number, each corresponding to an outer bract; but inasmuch as each is voluminously filled with flowers and bractlets, the general appearance is that of a series of heads with the stems going through the middle. Such an inflorescence is unknown in any of the other subgenera, in which the involucres are borne singly in cymes, or in true terminal heads.

3. *Early ruptured involucres.* The involucre itself is broadly campanulate, unangled (a further distinction from the subgenus *Oregonium*, to which *Clastomyelon* is most nearly allied), and deeply 5-partite. The expanding flowers soon rupture the involucre, however, so that at maturity it is flat and platelike, or in old material often appears as though composed of distinct lobes, thus masking the identity of the plant with *Eriogonum*.

4. *Hairy pedicels.* The pedicels of the individual flowers within the involu-

[2] From κλαστός, broken, and μυελόν, pith.

cre are definitely pilose. Although no general statement has been made in the literature concerning the pedicels in the various subgenera of *Eriogonum*, we find by study of the almost complete representation of recognized species in the National Herbarium, that they seem to be uniformly glabrous, except for a very few species, in which they bear minute glands. The hairs in *Clastomyelon* are often somewhat deciduous after maturity.

5. *Flask-shaped, crested fruits.* The fruit of *Clastomyelon* is very peculiar in form, being conspicuously bulbous-dilated at base and trilobate, each lobe bearing a conspicuous rounded crest, filled with pithlike tissue. At the middle the fruit is abruptly contracted, the upper portion being slender and sharply triangular. Although it is not possible to say at present that such fruits are not found in species of other subgenera, it seems likely that that is true. At least, in none of the species that we have examined has there been any approach to this condition.

The above mentioned characters by which *E. intrafractum* differs from all previously known species seem to us amply sufficient ground for the creation of a new subgenus, to take a place coördinate with the three other recognized subgenera. Additional characters of merely specific importance, which will separate the present species from others of the genus, are the tall leafless stems, usually more than one meter high and unbranched up to the inflorescence, the relatively large, long-petiolate basal leaves, uniformly short-pilose (but not at all tomentose) on both surfaces, the numerous accessory bractlets present in the inflorescence (including an involucre of three basally united bractlets present at the base of each involucre), the minutely pubescent perianth (ochroleucous when young, yellow and rose in age), deeply constricted at the middle and with flaring limb, and the unequal perianth segments. In most species of *Eriogonum* with unequal segments, the inner are shorter and narrower than the outer, but in *E. intrafractum* the reverse is true.

Eriogonum intrafractum Coville & Morton, sp. nov.

Herba perennis, caulibus erectis, altis, solitariis, teretibus, non ramosis, glaucis, fistulosis, demum interne perspicue articulatis; folia basalia, longe-petiolata, late oblonga obovatave, apice rotundata, basi cuneata, utrinque breviter pilosa; involucra in verticillis circum ramos inflorescentiae disposita, sessilia, aperte campanulata, 5-lobata, pubescentia, non angulata, mox fissa; florum pedicelli pilosi; perianthium ochroleucum, demum basi roseum apice luteum, basi rotundatum, medio constrictum, segmentis externe pubescentibus, exterioribus quam interioribus brevioribus et angustioribus; fructus basi bulboso-inflatus, trilobatus, lobis cristatis, medio abrupte contractus, apice angustus, triangularis.

Perennial herb with a thick woody taproot; stems erect, 0.9–1.2 m long, usually solitary, terete, up to 11 mm in diameter, unbranched except in the inflorescence, there two or three times subdichotomously (or rarely trichotomously) branched, glabrous, glaucous-green, fistulous, internally transversely articulate into short segments 3–9 or even 16 mm. long, the outer layer at length exfoliating, thus allowing the stramineous, moniliform articulations to fall off separately; leaves all basal, long-petiolate, the

petioles pale yellow, densely short-pilose, exceeding the blade in length, the latter broadly oblong or obovate, up to 7 cm long and 3.5 cm wide, rounded at the apex, cuneate at the base, yellowish or grayish green, membraneous, entire, plane, densely and uniformly short-pilose on both surfaces, the midvein and 3 or 4 prominent secondary veins pale yellow, prominently elevated beneath; secondary rosettes of leaves often borne at the base of the stem; bracts at the primary furcation of the stem whorled, about 5, ovate, acute, densely short-pubescent, deciduous; inflorescence subspicate in appearance, consisting of densely flowered involucres borne in whorls up the branches, or these solitary on the ultimate branches; bracts subtending each whorl of involucres three, free, oblong, about 3 mm long and 1.4 mm wide, sharply acute, pilosulous on both surfaces, fleshy, green; internal accessory bractlets of two kinds: (1) 3 bractlets at the base of each involucre, similar in shape and texture to the outer bracts but smaller and united at base and forming a single tripartite bract, (2) supernumerary bractlets (usually narrowly oblong) irregularly disposed between the outer bracts and the involucres; involucres sessile, openly campanulate, 5-lobed, about 3 mm long, pubescent on both surfaces, fleshy, not angled, the lobes ovate, erect, about 1.5 mm long, the tube ruptured in one or several places at maturity by the expanding flowers, the entire involucre then becoming flat and plate-like; pedicels of the flowers pilosulous, interspersed with numerous linear-oblanceolate pubescent bractlets, these sometimes fleshy and green; perianth ochroleucous, in age becoming rose at the base and yellow toward the apex, 3 mm long, rounded at the base, definitely constricted at the middle, there about 1.7 mm wide, flaring and about 2.2 mm wide at the apex, the segments minutely pubescent externally, the outer broadly oblanceolate, shorter and narrower than the inner, rounded at the apex, concave, the inner carinate below, plane above; stamens much shorter than the perianth segments, the filaments subulate, glabrous, adnate at the base to the perianth segments, the anthers oval, white; styles 3, slender, free, recurved; stigmas capitate; fruit triangular and flask-shaped, the much inflated base being expanded into three prominent lobes, abruptly contracted at the middle into a sharply triangular upper part, sparingly short-hairy when young.

Type in the U. S. National Herbarium, no. 1,631,285, collected in Titus Canyon, Grapevine Mountains, Death Valley, Inyo County, California, at about 2,000 feet altitude, Oct. 13, 1935, by M. French Gilman (no. 2120).

The following additional specimens, all from Death Valley, have been examined: Same locality, Apr. 25, 1932, *Coville & Gilman* 442; May 8, 1934, *Gilman* 1194; June 11, 1935, *Gilman* 1690. Death Valley Canyon, July 9, 1935, *Gilman* 1917. Also several unnumbered specimens collected in Titus Canyon by Mr. Gilman to show the articulations of the old stems.